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Microbes and the water nexus

In observance of World Water Day, *Nature Microbiology* calls attention to research avenues that run through freshwater microbiology.

World Water Day, a United Nations Observance, takes place on 22 March and calls attention to the myriad roles fresh water plays in life on Earth. The observance is in line with Sustainable Development Goal 6, which has sights set on attaining clean water and adequate sanitation for all. For many, access to safe, clean water makes it easy to take this resource for granted, but climate change, international conflict, natural disasters and issues related to infrastructure, development and agriculture can all cause water scarcity and pollution. It is estimated that more than two billion people around the globe do not have access to safe drinking water, and this number threatens to increase under future climate projections and with the demands of a growing global population.

World Water Day has taken place annually since 1994, with a different theme each year, for example focusing on the intersections of water and energy, culture, development, transboundary issues, cities or climate change. This year's theme, Leveraging Water for Peace, comes on the heels of a year during which international conflicts multiplied and climate-related issues, such as droughts, flooding and wildfires, were frequent occurrences. Water is an essential resource for life, and Leveraging Water for Peace highlights both how threats to access can compound or create new conflicts, and how ensuring safety, equity and cooperation around water availability can yield far-reaching positive impacts.

Safeguarding water resources in the near and long term will require action from all sectors of research. At *Nature Microbiology*, our inclination is to wonder how the smallest biological entities on Earth intersect every facet of the water nexus. Threats to water sanitation and pollution are often microbial in nature. Climate and land-use changes, as well as natural disasters, reshape freshwater systems with knock-on effects for the ecology[1,2] and transmission of bacterial, fungal, viral and parasitic pathogens, as well as for antimicrobial resistance. When it comes to attaining the objectives of Sustainable Development Goal 6, microbes must be taken into consideration. In this Editorial, we briefly highlight broad umbrellas of emerging research in freshwater microbiology that should be considered if we are to achieve these objectives.

Natural disasters represent the most rapid mechanisms by which freshwater resources can be affected, but the subsequent impact on microbial dynamics is not routinely considered. Flooding from severe storms as well as other natural disasters, such as earthquakes, that damage infrastructure rapidly alter the physical distribution of microbes and can result in exposure to a suite of potentially pathogenic microbes either from the environment or through compromised wastewater treatment facilities[3]. In the aftermath of flood-related disasters, fungi can colonize waterlogged buildings, leading to negative health implications after exposure[3]. Moving forward, investigations into how microbes impact the spread of antimicrobial resistance genes and research into how microbial dynamics intersect with environmental and social justice efforts should be a focus.

Even without a natural disaster, harmful algal blooms in freshwater systems can also rapidly, and unpredictably, threaten public health. Lakes are essential drinking water resources, but persistent high temperatures and nutrient runoff from land can trigger the proliferation of cyanobacteria that produce toxins that harm humans when consumed. As a result of these blooms, tap water can be rendered unsafe for millions of people for weeks at a time[4]. Historical records, recent observations and modelling efforts all suggest that the frequency and duration of these harmful algal blooms will increase in the future[4,5]. The conditions that favour harmful algal blooms could also pave the way for the increased abundance and activity of microbes that produce greenhouse gases such as methane and nitrous oxide, and climate modelling studies suggest that emissions from inland waters are likely to increase under future climate conditions[6]. Open questions in freshwater microbial ecology include a mechanistic understanding of how symbioses and interactions in these communities impact outcomes, for example interactions between methanogenic archaea that produce methane and methanotrophs that consume methane, or more work into the role of phages and how they impact these dynamics[7].

Global climate and land-use changes that impact freshwater systems also influence the spread of vector-borne diseases. The increased duration of warm and wet conditions, floods and deforestation all contribute to the increased spread of *Plasmodium*, the causative agent of malaria, as well as viruses such as dengue, chikungunya and Zika, all of which are transmitted by mosquitoes that breed in water. Extreme weather events and human disturbances can also impact the ecology of birds, which is exacerbating the spread of highly pathogenic avian influenza. These dynamics are discussed in two Comments in our recent focus issue on microbes and climate change[8,9]. In addition to calling for the mitigation of climate and land-use changes, another theme that emerges from these pieces is the need for those in power to take climate-related health impacts into account, to collaborate with microbiologists, to involve impacted communities in public-health discussions and to ensure that aid is equitably distributed, especially to the most vulnerable populations.

While the intersections of freshwater research and microbiology often take a negative slant, as a journal we believe that impactful research paves the way for actionable solutions. At *Nature Microbiology*, we want to showcase the best research in all areas that touch on freshwater microbiology, with the hope that it will fuel additional understanding and initiative. From basic research to policy and governmental decisions to international collaborations, we hope that increasing focus on microbes and freshwater resources will hasten the realization of World Water Day's goals.

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